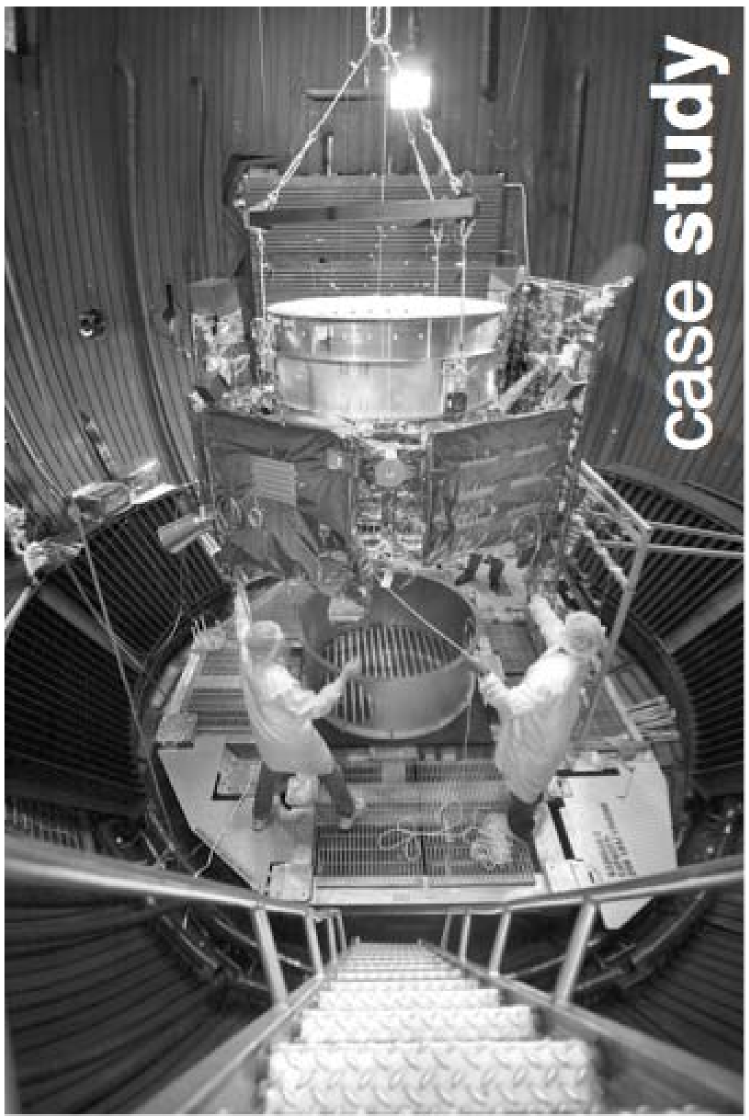
National Aeronautics and Space Administration

Academy of Program/Project & Engineering Leadership

Lunar CRater Observation and Sensing Satellite (LCROSS)



LRO Plus One

When NASA announced that the Lunar Reconnaissance Orbiter (LRO) would upgrade from a Delta II to a larger Atlas V launch vehicle, a window of opportunity opened for an additional mission to go to the moon. The Atlas V offered more capacity than LRO needed, creating space for a secondary payload.

The Exploration Sciences Mission Directorate (ESMD) posed a challenge to interested secondary payload teams: The chosen mission could not interfere with LRO, it could not exceed a mass of 1000 kilograms (kg), it could not go over a $79 million cost cap, and it had to be ready to fly on LRO's schedule. Of the 19 proposals submitted, ESMD chose the Lunar CRater Observation and Sensing Satellite (LCROSS) – a mission that sought to search for water on the moon by firing a rocket into the lunar surface and studying the debris resulting from the impact.

Dan Andrews, the LCROSS Project Manager, was charged with assembling a team that could develop a satellite on a shoestring while coordinating its efforts closely with LRO. "It could have been a real recipe for disaster," he said. "There were plenty of reasons why this mission should not have succeeded."

The Good Enough Spacecraft

From Andrews's perspective, the LCROSS spacecraft had to be "faster, *good enough*, cheaper." He made clear to his team from the beginning that LCROSS was not about maximum performance. "It was about cost containment," Andrews said. "LCROSS was not about pushing the technical envelope. It was about keeping it simple – keeping it good enough."

The LCROSS team had 29 months and $79 million to build a Class D mission spacecraft. (See below for a brief explanation of NASA mission risk classifications.) The low-cost, high-risk tolerance nature of the project led to a design based on heritage hardware, parts from LRO, and commercial-off-the-shelf components.

Class D Mission

"Class D" refers to NASA's mission risk classification system as described in NASA Procedural Requirements (NPR) 8705.4. All NASA missions are assigned a risk classification ranging from Class A ("All practical measures are taken to achieve minimum risk to mission success.") to Class D ("Medium or significant risk of not achieving mission success is permitted."). Class D missions like LCROSS have low-to-medium national significance, low-to-medium complexity, low cost, and a mission lifetime of less than two years.

LCROSS's status as a Class D mission did not preclude it from practicing risk management. "We were risk tolerant, but that doesn't mean we were risk ignorant," said Jay Jenkins, LCROSS Program Executive at NASA Headquarters. Unlike a Class A mission, LCROSS did not have the luxury of "buying down" all risks with its budget.

"With the LCROSS instrument testing, we shook, cooked, and cooled the mostly commercial-off-the-shelf parts that could potentially come loose during launch so that we were likely to have a tough little spacecraft, but we didn't test to failure," said Dan Andrews.

LCROSS consisted of a Shepherding Spacecraft (SSC) and a Centaur upper stage rocket. The SSC included a fuel tank surrounded by a repurposed EELV (Evolved Expendable Launch Vehicle) Secondary Payload Adaptor, also known as an ESPA ring. The ESPA ring was conceived by the Air Force Research Laboratory as a small satellite deployment system, but it had never been flown on a NASA mission or as a spacecraft bus. It has six bays that could hold up to six small satellites, but on LCROSS, those bays held the principal subsystems of the spacecraft. (See Figure 1.) This novel use of the ESPA ring offered a number of advantages. It was already tested, developed, and very sturdy, facilitating flexible, low-risk integration with the LRO mission on the "back" of LCROSS.

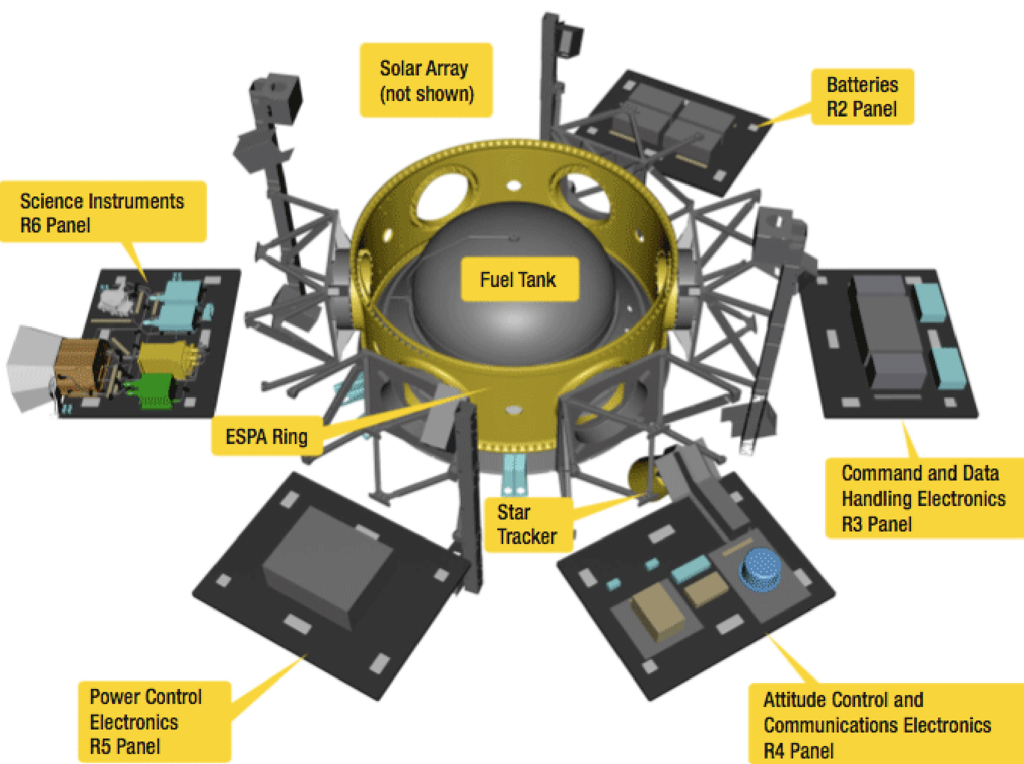


Figure 1. The LCROSS spacecraft employed a novel use of an ESPA ring.

The off-the-shelf payload instruments included imaging equipment found on Army tanks, carpet fiber recycling hardware, and instruments used to measure engine block temperatures for NASCAR. The components were repurposed for the LCROSS mission and tested in-house to the mutual benefit of NASA and the vendors. This was essential when minor tweaks had to be made to improve survivability of the instrument. The cost of these instruments was much smaller than traditional custom development of instruments, with the total instrument cost being about three percent of the entire mission cost.

Dan Andrews described this as a capabilities-driven approach. “The whole principle of LCROSS was, ‘If there are investments that the agency or industry have made and it’s something we can employ, then do it,’” he said.

Crossover and reuse of hardware between the LCROSS and LRO spacecraft allowed the two teams to learn from and with one another. Sometimes the teams worked in tandem, while at other times one team would be ahead of the other. “There were things that we missed that we either caught later, or missed and LRO caught, and vice-versa,” said LCROSS Project Systems Engineer Bob Barber. This helped to facilitate a cohesive relationship between the two missions.

While LCROSS was a Class D mission, LRO, a Class B/C mission, and the Atlas V rocket, a Class A vehicle, were held to much higher standards. The launch vehicle provider expressed concern that LCROSS might interfere with the performance of LRO, the primary payload. “It became a lowest common denominator problem,” said Andrews.

LCROSS didn’t have the budget to meet the requirements of a Class A mission, nor was it supposed to. Andrews raised the issue with the program office, which eventually facilitated some additional testing of its structural hardware to ensure that LCROSS satisfied the concerns of all the stakeholders in the mission.

The Team

Andrews knew he had to establish trust with both the LRO team and Northrop Grumman (NG), the contractor building the spacecraft.

The LRO team, which was based at the Goddard Space Flight Center (GSFC), was understandably cautious about LCROSS hitching a ride with them to the moon. Andrews quickly moved to identify an LCROSS engineer to take up residence with the LRO team to facilitate quick dialogue and build trust between the two missions, which worked perfectly. With good lines of communication and the crossover of hardware, the two teams started to view each other as resources and “work[ed] together like a team this agency hasn’t seen in a long time,” said Andrews. “These good relationships really pay off when things get tough.”

Given the tight schedule and limited budget, the partnership with NG was also essential. Neither Andrews nor NG Project Manager Steve Carman had ever managed a spacecraft development before, though both had run space flight hardware development projects. “We were both kind of new to the spacecraft side of things, but I told my management to provide me with an outstanding team, and Dan did the same,” said Carman.

Andrews noted that the key was to find common purpose between NASA and NG, so that we are collectively and individually interested in seeing this mission be successful while meeting the challenging cost cap. Carman, who had spent his career managing payload development projects, had a different vantage point. “This spacecraft was big compared to what I was used to building,” he said.

Over the first six months, as the project underwent a number of contractual changes related to acquisition means, Andrews and Carman began to develop a mutual trust. “Ultimately communication was the hallmark of the partnership,” said Carman. “The partnership was not something where we said, ‘Sign here—we are partners.’ It was something that grew out of a relationship, and we began to see we could see how you could gain insight into how we were operating. We showed them as we went along that we were indeed capable of doing this faster than anything we had done here.”

For Dan Andrews, the trust grew out of a shared understanding of the way that both organizations traditionally operated. “We talked plainly about budgets. We talked plainly about the NASA construct, and then they talked plainly about how hard it is to move NG’s heavy institution,” he said. “I was not holding anything back in terms of what I was sharing with them and I think that set a tone within NG that they behaved similarly.”

By the time of the Preliminary Design Review, a cooperative dynamic had been established that went beyond business as usual. “It was an ‘open kimono’ type relationship where everything was kind of on the table,” said Bob Barber. “We wanted a really open and honest relationship with them.” NASA team members took part in NG’s risk management boards and were welcome to attend staff meetings.

The relationships didn’t end when people left the project. Both NASA and NG experienced turnover, which could have hurt the project dramatically. In this case, though, several former team members kept in touch with their successors. “That’s when you know a team is more than just coming to work and doing stuff,” said Barber. “There was a friendship and a professionalism that was there. I’ve worked on projects that when guys leave you can’t get information out of them to save your life.”

Tightening the Schedule

To meet the aggressive schedule demands of LCROSS, Carman established a baseline project plan with very little margin, and then challenged key team members to consolidate their subsystem schedules. “Basically I said, ‘I think you’ve got some contingency in your schedule. I know you think you need every minute of it, but I’ll bet you can move faster,” Carman said. “As they went along, we kept finding ways to improve the schedule.”

For example, the lead propulsion engineer came back to Carman and said she could pull six weeks out of the propulsion schedule. As the work progressed, the team continued to make gains, eventually ending up eight weeks ahead. “We had a schedule that was based on ‘When do you need it?’ and I was saying, ‘How fast can you do it?’ And so people found ways to modify the processes,” said Carman.

Expediting the Review Process

The LCROSS schedule wouldn’t allow time for a lengthy review process throughout the life cycle. Andrews and Carman orchestrated a compromise that reduced the number of NG internal reviews, and made the review process more collaborative.

Prior to each key milestone review, the teams held a peer review, which they called a design audit. Since both NASA and NG wanted to send managers and experts to check on the project, Pete Klupar, head of the Independent Review Board for NASA, jokingly threatened that he would give a short quiz at the beginning of the reviews to determine which stakeholders had done their pre-meeting reading and study. The point of this dialogue was to reinforce that the reviews are not there to educate the stakeholders, but to derive value from their expertise. The project team would happily discuss and questions, but it was not their job to educate an unprepared reviewer.

By inviting stakeholders to the Critical Design Audit near the end of Phase C, the team experienced a relatively smooth and quick Critical Design Review. This process was so successful that the team then applied the same concept to the validation and verification process by instituting Verification Compliance Audits. “This very informal, hands-on, roll up the sleeves, no ties allowed, stakeholder involvement right from the get-go is all reflective of that collaborative process,” said Jay Jenkins.

Risk Tolerance in Practice

The LCROSS team had to determine how far it was willing to go with risks. Too many changes to the spacecraft could turn an acceptable risk into one that was even bigger.

LCROSS held monthly risk management boards, increasing the frequency to biweekly if necessary. The meetings were painful but essential. “No one was having fun, but everyone there knew that this was a very necessary thing,” said Dan Andrews.

Early in the project, the team discovered that a capacitor responsible for protecting voltage input to a field programmable gate array (FPGA) was identical to one that failed in the power system. If the capacitor regulating voltage to the FPGA failed, the FPGA would experience voltage stress and it was unclear how much stress the FPGA could handle. Loss of this FPGA would be a fundamental, unrecoverable problem, potentially ending the mission altogether.

“All of the probability analysis said this should be very low risk,” said Bob Barber, “but it was a mission killer if the wrong one failed.”

The capacitor was already built into a box that had passed all of its testing and was performing fine. The problem was that the location of the capacitor did not enable remote viewing of its condition. With little room for error in the budget or schedule, the team didn’t want to invite more risk by opening up a tested flight box to test the capacitor, which could very well be fine. This was one of the most challenging risk trades this project would have to navigate.

It wasn’t until a change in the Atlas V launch manifest led to a delay in the launch date that the LCROSS team had the time and resources available to revisit its risk list. The team determined that the risk of going in to test the capacitor was lower than doing nothing at all.

“We took a risk [opening the box] to try and eliminate what we felt was our highest risk [the capacitor]. Then we ended up closing that risk, and we took it off the plate,” said Barber. The capacitor was performing fine, and the project’s top risk was retired.

Against long odds, the project met its cost and schedule constraints and passed its final reviews. It was time for launch.

Low on Fuel

Fires lit and smoke pluming, the Atlas V launched LCROSS to the moon on Tuesday, June 18, 2009. One hour after launch, LRO, sitting at the top of the stack, separated from the rocket to head toward the moon and insert itself into lunar orbit. LCROSS took another path.

Two months into its journey to the moon, LCROSS experienced an anomaly while the spacecraft was out of contact with NASA’s Deep Space Network (DSN). Data from the spacecraft’s Inertial Reference Unit, its onboard gyro and primary means of measuring rotation rates around each axis for attitude control, experienced a data fault. This led to a chain of actions, resulting in the spacecraft’s thrusters firing propellant almost continuously. The operations team noticed this once the spacecraft was back in contact with the DSN. Engineers quickly identified a probable root cause and other contributing factors. Immediate steps were taken to stop the thrusters from continuing to fire and to prevent a similar occurrence again. The team also adopted new ultra-low fuel consumption means to conserve propellant until the lunar impact. While there was no precise way to measure what remained in the tank, analysis showed that LCROSS had expended 150 kg of its 200 kg of propellant. The specific cause of the anomalous data fault remained unresolved, but the engineering teams determined that even under worst-case conditions, the spacecraft still had minimally enough propellant to achieve full mission success.

Smashing Success

LCROSS journeyed for another six weeks before lining up on its collision course with the moon. Once in position, the Centaur rocket separated from the SSC and barreled down on the moon's Cabeus crater, where it crashed at twice the speed of a bullet. Following minutes behind the Centaur, the SSC took pictures, flying through the vapor cloud created by the LCROSS impacter, analyzing the debris, and sending the data back to Earth before it too smashed into what turned-out to be a very soft, porous crater floor. The whole sequence lasted a mere four minutes and nineteen seconds, going off without a hitch.

Teaching Notes

This case study has been designed for use in a classroom setting. Please read the full case prior to in-class discussion to allow ample time for analysis and reflection.

Consider the following questions:

- How did the constraints of the mission shape the project management challenge?
- What role did communication play in building a team that could work within the mission constraints?
- How did the project manage its approach to risk?

Ask participants to discuss in small groups, encouraging them to draw analogies to their own experience and develop as many interpretations as possible. The small groups will then reconvene as a large group and share their conclusions.